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INSULATING BUILDINGS AGAINST TRANSPORTATION NOISE

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Abstract

Transportation noise contains significant low frequency components. It is difficult to sound insulate buildings against transportation noise because wall cavities are only effective in increasing sound insulation above the mass-air-mass resonance frequency. Stud walls can also have a significant structural resonance in this low frequency range, although it is not yet clear if this is significant in the field. This paper gives typical diesel electric locomotive traffic noise, road traffic noise, aircraft traffic noise and other rail traffic noise spectra. The paper examines the sound insulation of measured wall sound insulation spectra against these typical transportation noise spectra using A-weighted sound level reduction. This will be compared to the $R_w + C_{tr}$ and R_w values of the walls. Another problem with low frequency sound insulation is the large uncertainty in both laboratory and field measurements. The adoption of $R_w + C_{tr}$ in the Building Code of Australia will make the common single number rating more appropriate for transportation noise.

Nomenclature

f_{mam}	Mass-air-mass resonance frequency
m_1	Mass per unit area of wall leaf 1
m_2	Mass per unit area of wall leaf 2
d	Width of the cavity
ρ_0	Density of air
c	Speed of sound in air

Introduction

The principles of sound insulation are not always well understood. Even acousticians tend to look at sound insulation through “single number rating glasses”. This paper commences with a non mathematical introduction to the principles of sound insulation. Most research in transportation noise is understandably directed towards estimating or measuring A-weighted sound pressure levels. To study insulation of transportation noise the sound spectra shapes also need to be known. This paper gives the spectrum shape for diesel electric locomotives, and a number of other road, rail and aircraft transportation noise spectrum shapes.

The mean, standard deviation, maximum and minimum values of A-weighted sound level attenuation relative to the weighted sound reduction index R_w across 104 sound insulation spectra are given for the different transportation noise spectra.

The diesel electric locomotive spectra have significant A-weighted sound energy below the 100 Hz third octave band. Unfortunately there can be a large variation in sound insulation measurements in this frequency range.

For cavity walls careful consideration must be given to mass-air-mass resonance. A structural resonance at about 125 Hz can cause decreases in laboratory measurements of the sound insulation of wooden stud cavity walls but appears to be not so deleterious in the field.

Sound Insulation

There are no magical sound insulation materials. For good sound insulation, the building partition or facade must be airtight and have a high mass per surface area. Because, to a first approximation, the cost of building materials is proportional to their mass, good sound insulation is expensive. Unfortunately, increasing the thickness of a building element to increase its mass per surface area also increases its bending stiffness. This extra bending stiffness can enable the noise to by-pass the effect of the increased mass by shifting the critical frequency dip to a lower frequency. This means that it may be better to add extra mass per surface area by adopting a double wall construction. Experiments show that walls with more than two leaves do not produce better sound insulation than a double wall of the same materials, mass per surface area and total wall thickness. If multiple layers of sheet materials are being used to increase the mass of a wall leaf, they should be spot glued together with the minimum structurally required number of glue points. This will keep the high frequency bending stiffness of the wall leaf as low as possible.

Like the air in a car tire, the air in a wall cavity acts like a spring. Making the air cavity less stiff by increasing the distance between the two wall leaves can reduce the amount of sound that an air cavity transmits. The thickness of the air cavity needed depends on the mass per surface area of the wall leaves and the frequency of the sound. The lower cavity thicknesses apply to the more massive wall leaves.

It is also necessary to deaden the reverberation of sound that can occur in the wall cavity by using at least a 50 mm thickness of sound absorbing material, such as a porous material of medium to high density. In particular, roof spaces should be fitted with porous thermal insulation such as glass fiber, mineral wool or cellulose fiber. This should also be done for thermal purposes. It will increase thermal comfort and reduce heating and cooling energy costs. Reflective foil insulation is not suitable for acoustical purposes. Obviously sound insulation cannot fill the cavity in the case of double-glazing, although the revels can be lined. Care must be taken that the sound absorption does not bridge the cavity in masonry walls. If it does, it may enable water to cross the cavity. Users of glass fiber and mineral wool should consult the National Occupational Health and Safety Commission's "Synthetic Mineral Fibers - Guide and Code of Practice." For acoustical use in wall cavities, these materials may be sealed using thin plastic film. Special acoustical design is needed if this technique is to be used in acoustical attenuators.

Once the air cavity has been deadened, most of the sound transmission between the wall leaves occurs via the structural connections between them. As in the case of the air cavity, decreasing the stiffness of the structural connections can reduce this structural transmission. Lightweight steel studs work well. For other walls, at least one of the wall leaves can be mounted on resilient channel bars. For brick cavity and brick veneer walls, the minimum number of brick ties needed for structural reasons should be used in order to reduce the structural coupling.

Sandwich panels are not very suitable for sound insulation. Viewed as single leaves, they normally have low mass per surface area and high bending stiffness. Viewed as double walls, the sandwich material is always stiffer than the same thickness of air.

The low frequency nature of typical external noise means that cavity construction may not be more effective than a single wall with the same mass per surface area, unless very wide cavities are used. In particular single glazing may be as effective as double-glazing with a narrow air gap.

Windows and doors are often the weakest link in a building partition or envelope. It will often be necessary to use double-glazing. Doors and opening windows need to be very well sealed. Windows, and doors at the top and sides, should close onto compressible refrigerator type airtight seals. If a raised doorsill can be tolerated, a similar seal can be used on the bottom of the door. Otherwise a seal that automatically lowers itself when the door closes must be built into the bottom of the door. Doors will probably need to have a solid core. Normal doors are not thick enough to be able to take advantage of cavity construction for increasing their sound insulation. Double-glazing units designed specifically for good thermal insulation should be avoided because the spacing of their glass leaves is normally too small to obtain the sound insulation benefits of double-glazing. However they may still be worthwhile using because of their good sealing. Laminated glass does not perform significantly better acoustically than plain glass of the same mass per surface area.

Wall and roof vents not required by the building code should be blocked up. It may also be necessary to seal the top and bottom of the cavity in cavity brick and brick veneer walls. High sound insulation facades will require sound attenuators on their sub floor vents. Single leaf masonry walls can have their sound insulation reduced by their high porosity. They are often rendered to reduce the porosity. For external use they also have to be treated to stop rainwater penetration. The reverberation in the rooms inside the building must also be deadened. However any room with soft furnishings will have sufficient sound absorption already.

Opening of windows or doors will by-pass the sound insulation of the rest of the building envelope. This means that a sound insulated building will probably have to be mechanically ventilated via acoustical attenuators. These acoustical attenuators usually consist of ducts internally lined with sound absorbing material such as glass fiber or mineral wool, possibly behind some acoustically transparent lining like perforated metal or very thin plastic film. In most parts of Australia, especially during summer, the closed building will need to be cooled. This adds substantially to the running costs of the building. Closing the building also means that it is not possible to lead the very popular indoor - outdoor lifestyle.

Transportation Noise Spectra

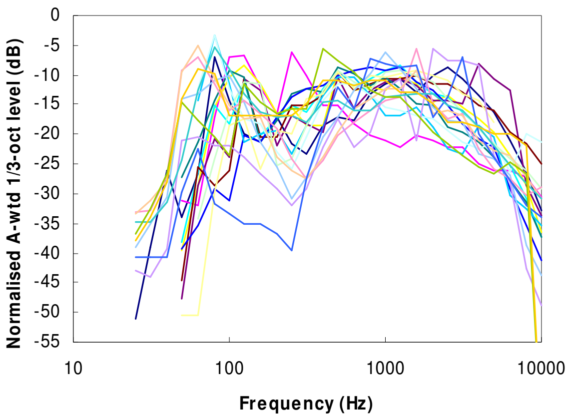

Figure 1. Twenty normalized A-weighted third octave diesel electric locomotive spectra.

The difficulty of insulating against noise depends on the shape of the frequency spectrum of the noise. Twenty A-weighted third octave spectra of diesel electric locomotives have been collected [1 - 4]. These spectra were normalized so that they summed to zero decibels.

These normalized A-weighted third octave spectra are shown in Figure 1. It should be noted that because the spectra are A-weighted, Figure 1 shows that most of the spectra have significant low frequency energy.

These spectra were then averaged in both the energy domain and in the decibel domain. The spectrum obtained by averaging in the decibel domain was then renormalized so that it summed to zero decibels. These two average spectra are compared with other traffic noise spectra in Figure 2. The energy domain averaged spectrum is denoted by “RailDieselE”. The renormalized decibel domain averaged spectrum is denoted by “RailDieselD”. The French road traffic noise spectrum [5] is denoted by “FrenchRoad”. The only reason that the French road traffic noise spectrum is not used in the calculation of $R_w + C_{tr}$ is that it is only available down to 100 Hz. The spectrum used to calculate $R_w + C_{tr}$ [6, 7] is the average of eighteen road traffic noise spectra from Copenhagen and Gothenburg [8]. It is mixed urban road traffic at 50 km/hr with about 10% of heavy vehicles. This spectrum is denoted by $R_w + C_{tr}$ in Figure 2. It was used in the calculation of $R_w + C_{tr}$ because it was available down to 50 Hz and enabled the extension of $R_w + C_{tr}$ down to 50 Hz if desired.

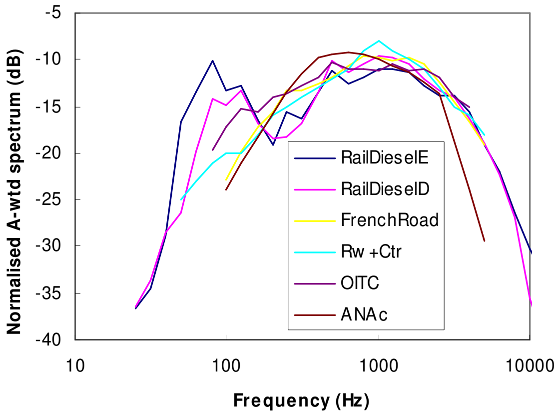

Figure 2. Comparison of traffic noise spectra.

Also shown in Figure 2 is the aircraft noise spectrum used to calculate the aircraft noise attenuation of a building component in earlier versions of the Australian Standard AS 2021 on building siting and construction for protection against aircraft noise intrusion [9]. This spectrum is denoted by “ANA_c” and is fairly similar to the two road traffic noise spectra, “FrenchRoad” and “$R_w + C_{tr}$”. The “ANA_c” spectrum is a rounding of the average aircraft noise spectrum derived by Dunn [10]. Figure 2 also shows the Outdoor-Indoor Transmission Class spectrum [11] which is denoted by “OITC”.

As well as the $R_w + C_{tr}$ spectrum, Nordtest Method NT ACOU 061-1987 [8] gives six other traffic noise spectra. These Nordtest spectra are compared to the diesel electric locomotive spectra in Figure 3.

“Road High” is “mixed highway road traffic at 90 km/h and with 10% heavy vehicles”. It is the “mean value of a great number of measurements on smooth and rough textured surfaces”.

“Rail Low” is “normal railway traffic at low speeds”.

“Rail High” is “normal railway traffic at high speeds”.

“Rail Other” is railway traffic not in the previous two categories.

“Air Jet” is the mean value of 59 DC-9 take-offs at 500 m from the Kastrup airport runway.

“Airprop” is the mean of 10 different types of propeller aircraft.

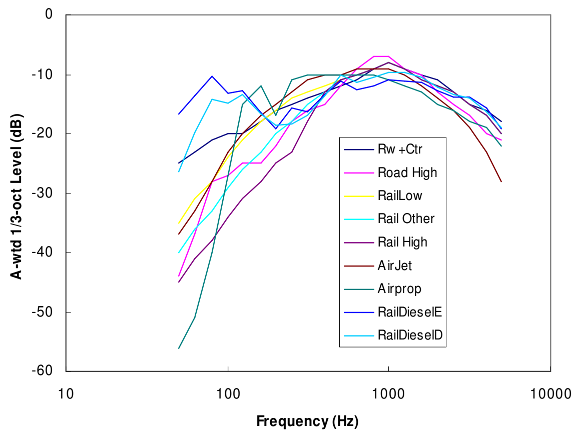

Figure 3. Comparison of the Nordtest traffic noise spectra with the diesel electric locomotive spectra.

Table 1. Normalized A-weighted railway traffic noise spectra.

f Hz	DE	DD	RLL	RLO	RLH
25	-36.7	-36.5			
31.5	-34.6	-33.7			
40	-28.8	-28.5			
50	-16.7	-26.4	-35	-40	-45
63	-13.5	-19.9	-31	-36	-41
80	-10.2	-14.2	-28	-33	-38
100	-13.3	-14.9	-24	-29	-34
125	-12.7	-13.3	-21	-26	-31
160	-16.5	-16.8	-18	-23	-28
200	-19.1	-18.5	-16	-20	-25
250	-15.6	-18.3	-14	-18	-23
315	-16.3	-16.9	-13	-15	-18
400	-13.5	-13.5	-12	-13	-13
500	-11.2	-10.2	-11	-11	-11
630	-12.7	-11.4	-10	-10	-10
800	-11.9	-10.5	-9	-9	-9
1000	-11.0	-9.7	-8	-8	-8
1250	-11.1	-9.7	-9	-9	-9
1600	-11.3	-10.4	-11	-11	-11
2000	-12.8	-12.1	-12	-12	-12
2500	-13.8	-13.3	-13	-13	-13
3150	-13.9	-14.1	-15	-15	-15
4000	-15.7	-16.3	-17	-17	-17
5000	-19.2	-19.0	-20	-20	-20
6300	-22.0	-22.4			

8000	-26.5	-26.9
10000	-30.3	-35.5
12500	-33.4	-40.4

The first thing to note is that the relative low frequency content of traffic noise decreases with increasing speed. The second thing to note is that the Scandinavian railway noise spectra have much less low frequency content than the Australian and North American diesel electric locomotive spectra.

A number of normalized A-weighted railway traffic noise spectra are tabulated in Table 1. They are RailDieselE (DE), RailDieselD (DD), Rail Low (RLL), Rail Other (RLO) and Rail High (RLH).

Table 2. Normalized A-weighted road traffic noise spectra.

f Hz	RDL	RDH	RDA	RDF
50	-25	-44		
63	-23	-37		
80	-21	-28		
100	-20	-27	-17.1	-22.8
125	-20	-25	-16.2	-19.8
160	-18	-25	-14.7	-17.1
200	-16	-22	-13.4	-15.6
250	-15	-18	-12.9	-13.3
315	-14	-16	-13.6	-13.3
400	-13	-15	-13.5	-12.5
500	-12	-12	-13.2	-11.9
630	-11	-9	-10.9	-10.6
800	-9	-7	-9.5	-9.5
1000	-8	-7	-8.9	-9.7
1250	-9	-9	-9.5	-10.1
1600	-10	-10	-10.6	-9.7
2000	-11	-13	-12.1	-10.5
2500	-13	-15	-13.5	-12.4
3150	-15	-17	-14.9	-14.5
4000	-16	-20	-16.4	-16.7
5000	-18	-21	-18.4	-19.2

Table 3. Normalized A-weighted air traffic noise spectra.

f Hz	AJ	AP	ANAc
50	-37	-56	
63	-33	-51	
80	-28	-40	
100	-23	-27	-24.0
125	-20	-15	-21.0
160	-17	-12	-18.3
200	-15	-17	-15.8
250	-13	-11	-13.5
315	-11	-10	-11.5
400	-10	-10	-9.7
500	-10	-10	-9.4
630	-9	-10	-9.3
800	-9	-10	-9.5
1000	-9	-11	-9.9
1250	-10	-12	-10.6
1600	-12	-13	-11.4
2000	-14	-15	-12.5
2500	-16	-16	-13.6
3150	-19	-18	-18.7
4000	-23	-19	-23.9
5000	-28	-22	-29.4

A number of normalized A-weighted road traffic noise spectra are tabulated in Table 2. They are Road Low ($R_w + C_{tr}$) (RDL), Road High (RDH), RoadAust (the Australian road traffic noise spectrum derived and used by Dunn [10]) (RDA) and FrenchRoad (RDF).

A number of normalized A-weighted air traffic noise spectra are tabulated in Table 3. They are Air Jet (AJ), Airprop (AP) and ANA_c.

OITC

In January 1997, the author was commissioned by the Australian Window Association (AWA), formerly the Residential Window Association (RWA), to develop an acoustic certification scheme for windows and glass doors. While writing the first and second drafts, the author was not aware that the second edition of ISO 717-1 [6] had just been published on the 15 December 1996. The first edition of ISO 717-1 did not contain spectral correction terms, so it could not be considered for use. Because he did not want to adopt yet another different spectrum, the author considered using ANA_c and OITC. He decided on OITC because it agreed moderately well with the average traffic noise spectrum used by Dunn [10]. Also the aircraft take-off noise spectra measured by Robert Bullen (private communication) suggested that the ANAc spectrum should be extended to a lower frequency and have its low frequency values increased. While writing the third draft [12], the author considered changing to $R_w + C_{tr}$, but rejected the idea because of the better agreement of OITC's spectrum shape with Dunn's [10] average of locally measured traffic spectra.

Later, under pressure from international colleagues, the author looked again at the OITC spectrum shape. The OITC spectrum (Walker [2]) is the average of aircraft take off, freeway and railway spectra. The author was surprised to discover that its aircraft take off spectrum had more low frequency content than its freeway spectrum. It also has more low frequency content than the aircraft noise spectrum in AS 2021-1994 [9]. The author has been told by members of Standards Australia's EV/11 committee, which is responsible for AS 2021, that the current wisdom is that the average aircraft noise spectrum in AS 2021-1994 is "about right". This has been confirmed by his colleague Narang (personal communication), who was involved with the Sydney Aircraft Noise Insulation Project (SANIP). The reference for Walker's aircraft noise spectra is Raney and Cawthorn [13]. The only spectral information in [13] that looks at all similar to the aircraft spectrum used by Walker is the bottom graph of Fig. 34.6 in [13] which pertains to the time 10 seconds after the aircraft is overhead. This time was probably chosen because it is close to the middle of the over all sound pressure time history. This spectrum was measured "during take off for a commercial jet aircraft powered by four low-bypass-ratio turbofan engines, measured at a location 5500 m (18,000 ft) from brake release (the start of ground roll) with the aircraft at an altitude of approximately 350 m (1100 ft)." Given the change in aircraft noise spectra, this spectrum is probably no longer relevant. Walker's aircraft noise spectrum appears to be a smoothed version of this spectrum given by Raney and Cawthorn.

The reference for Walker's road traffic noise spectrum is Scholes et al. [14]. Surprisingly the spectral information in this paper is octave band data. It is not clear how Walker extrapolated the octave band data to third octave band data. The other surprise is that it is United Kingdom rather than North American data.

The railway spectrum is from unpublished United States Gypsum Corporation test data. It is fairly irregular in shape. Thus there is probably not much averaging involved with this spectrum. All this new information casts some doubt on the current validity of the OITC spectrum.

The author then made more inquiries about the Australian road traffic noise spectra in Dunn's paper [10]. Subjectively, the Canberra measurements were effected by low frequency rumble from distant traffic crossing a busy bridge across Lake Burley Griffin. The Australian Academy of Sciences, where the Canberra measurements were made, sits on relatively high ground overlooking Lake Burley Griffin. The new freeway, which was the reason for the measurements, passes through a tunnel in this high ground. The Rohans Road measurements in Melbourne were made on a secondary road, and may have been affected by low frequency noise from more distant major roads.

The Australian road traffic spectra were then compared to a number of international road traffic spectra [5, 8, 14-22]. Most of the international road traffic noise spectra had less low frequency energy than the Australian road traffic spectra. This cast further doubt on the Australian road traffic spectra which had been used to support the OITC spectrum shape.

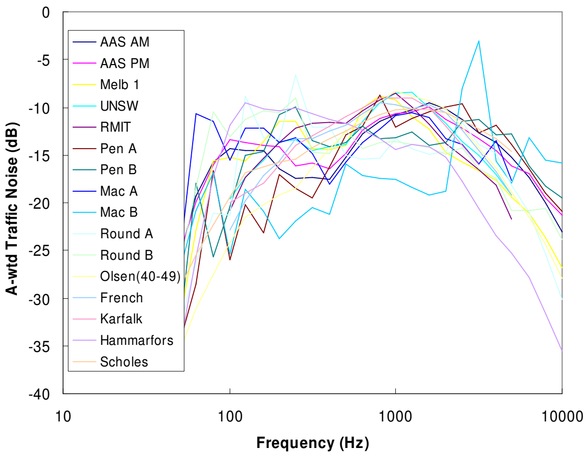

Figure 4. Sixteen normalized A-weighted third octave road traffic noise spectra.

Figure 4 shows 11 Australian and 5 international normalised A-weighted road traffic noise spectra. The first five spectra were used by Dunn [10] to derive his Australian road traffic noise spectrum. The next six spectra were rejected by Dunn because they are the maximum values in each frequency band of the spectra of one second samples over a 10 minute time period. The Mac B spectrum shows why Dunn rejected them.

The author was also concerned about the greater uncertainty in sound insulation measurements at low frequencies. Also a lot of existing sound insulation data is only available down to 100 Hz. After considering all the above information, the author has recommended that the AWA draft acoustic certification scheme change from using OITC to $R_w + C_{tr}$. The adoption of $R_w + C_{tr}$ in the Building Code of Australia [23, 24] makes this a sensible choice.

The Effect of Spectrum Shape

Dunn [10] compared the dB(A) reductions for aircraft and traffic noise with the STC rating for 104 different building elements. He "found, on average, that aircraft noise and traffic noise is attenuated by 4.6 and 6.0 dB respectively, less than the numerical value of the appropriate STC rating." Dunn's average values of 5 and 6 dB respectively (rounded to the nearest 1 dB) were used as corrections to tables of STC values in the Australian Standards AS 2021-1994 [9] and AS 3671-1989 [25]. These differences are only correct on average. They have large variations, which make STC unsuitable for ranking the sound insulation of facades.

The author has used the same spectra as Dunn and calculated the mean and standard deviation for most of the spectra showed in Figures 2 and 3. Results for Dunn's road traffic noise spectrum are also shown in Table 4 as RoadAust and results for his aircraft traffic noise spectrum correspond to the ANA_c results in Table 4. There are slight differences because the ANA_c spectrum is rounded to the nearest decibel and Dunn performed his calculations for sub-averages of the spectra and then averaged his results.

Table 4. Attenuation of A-weighted sound level (or STC) relative to R_w across 104 sound insulation spectra as a function of noise spectrum shape.

Spectrum	Mean	Stddev	Max	Min
R_w+C_{tr}	-4.5	1.9	-1.0	-10.0
ANA_c	-4.8	1.8	0.0	-9.0
R_w+C	-1.4	0.8	0.0	-4.0
STC	-0.2	0.6	1.0	-3.0
RailDieselE	-7.2	3.5	-1.0	-16.5
RailDieselD	-6.2	3.1	-0.9	-15.0
FrenchRoad	-4.6	1.9	-0.7	-10.1
RoadHigh	-2.0	0.8	0.1	-4.4
RailLow	-4.4	1.6	-1.0	-9.2
RailOther	-2.2	0.8	0.0	-4.5

RailHigh	-0.7	0.9	1.1	-3.2
AirJet	-5.2	1.9	-0.7	-10.2
AirProp	-6.7	2.7	-0.6	-14.0
RoadAust	-6.1	2.7	-1.1	-13.5

Although these spectra only go down to 100 Hz, the results are still very interesting. The two diesel electric locomotive spectra, the propeller aircraft spectrum and Dunn's Australian road traffic noise spectrum have the smallest mean attenuations and the largest standard deviations. Going to increasing attenuations and smaller standard deviations, the jet aircraft spectra come next, followed by the European road traffic noise spectra and finally the Scandinavian rail noise spectra. Both the Scandinavian road and rail traffic noise spectra show increasing attenuation with increasing traffic speed.

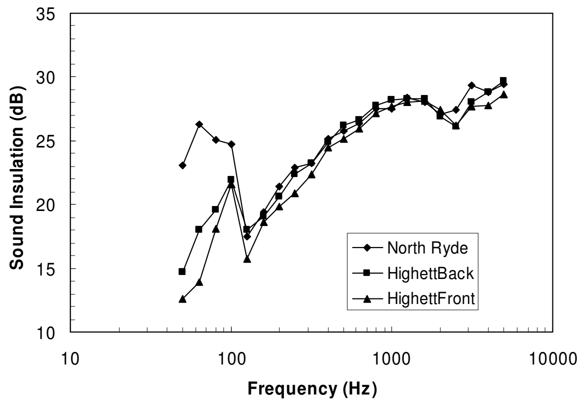

Figure 5. Comparison of sound insulation measurements at Highett and North Ryde.

Low Frequency Sound Insulation

The diesel electric locomotive spectra show considerable A-weighted sound energy below the 100 Hz third octave band. Clearly this needs to be taken into account in design. Unfortunately there is considerable variation in low frequency sound insulation measurements in both the field and the laboratory.

Figure 5 shows measurements of the sound insulation of a transom window measuring 2100 by 1800 mm. The initial measurement was made as part of a series of sound insulation measurements on glass doors and windows in the CSIRO acoustical laboratory at North Ryde. Because all these measurements showed a pronounced dip in their sound insulation at 125 Hz which could not be explained, the transom window was shipped to the CSIRO acoustical laboratory at Highett and re-measured. At North Ryde the transom window was measured with its glass about 100 mm in from the front of the opening in which it was mounted. At Highett it was initially installed by error the opposite way around with the glass almost flush with the opening in which it was installed. It was then installed the same way as at North Ryde and re-measured. There is reasonable agreement between all the measurements at and above 125 Hz. Below 125 Hz there are significant differences between North Ryde and Highett. Below 100 Hz the two different installations at Highett also differ.

Gibbs and Maluski [26] discuss the sound insulation of dwellings at low frequencies and give references to a number of recent papers on this topic.

Mass-Air-Mass Resonance

Given the uncertainty in low frequency sound insulation measurements, if one is designing sound insulation at low frequencies it is important to calculate the normal incidence mass-air-mass resonance frequency and make sure that this is significantly below the frequency bands with significant amounts of sound energy. If it is not possible to achieve this outcome, it is probably better to go for more massive monolithic construction.

The normal-incidence mass-air-mass resonance frequency f_{mam} Hz is given by

$$f_{mam} = \frac{1}{2\pi}\sqrt{\left(\frac{\rho_0 c^2}{d}\right)\left(\frac{m_1 + m_2}{m_1 m_2}\right)} \tag{1}$$

In Equation (1), m_1 kg/m^2 and m_2 kg/m^2 are the mass per unit area of the two wall leaves, d m is the width of the cavity between the two wall leaves, $\rho_0 \approx 1.2$ kg/m^3 is the density of air and $c \approx 343$ m/s is the speed of sound in air.

Bradley and Birta [28] point out that the stiffness of typical resilient channel bars is equivalent to that of a 160 mm air cavity. Thus resilient channel bars move the mass-air-mass resonance to a higher frequency than that in walls with no structural connections between the wall leaves. Rigid connection between the wall leaves effectively moves the mass-air-mass resonance to the frequency of the structural resonance discussed in the next section.

Wood Stud Exterior Walls

Bradley and Birta [28] have shown that the sound insulation of wood stud exterior walls can be significantly degraded by a structural resonance if the two wall leaves are rigid coupled by the wooden studs. They explain this structural resonance in terms of the analysis conducted by Lin and Garrelick [29]. The effects of this resonance can be reduced by structurally isolating the two wall leaves with resilient mounts, thin steel studs, staggered studs or double studs. The frequency of the resonance is about double the calculated mass-air-mass resonance and it reduces in frequency as the rigid stud spacing is increased and as the depth of the rigid studs is increased.

Bradley and Birta [30] report the results of laboratory sound insulation measurements on typical Canadian building facades. These measurements showed the structural resonance at 125 Hz. However field measurements (Bradley, Lay K and Norcross [31], Bradley [32]) with actual aircraft noise showed little effect due to this structural resonance.

Conclusions

A-weighted transportation noise spectra can have significant low frequency sound energy. There is considerable variability between different A-weighted transportation noise spectra. Diesel electric locomotive and propeller aircraft spectra have the most relative low frequency content. The relative low frequency content decreases as we move to jet aircraft spectra, to European road traffic noise spectra and finally to Scandinavian rail noise spectra. The Australian road traffic noise spectrum use by Dunn to calculate the – 6 dB correction to Sound Transmission Class (STC) in AS 3671 appears to be an outlier. The aircraft noise spectrum which gives the Outdoor-Indoor Transmission Class (OITC) spectrum its large low frequency content also appears to be an outlier.

Low frequency sound insulation measurements can show considerable variability. For good low frequency sound insulation, the normal incidence mass-air-mass resonant frequency should be significantly below the frequency bands with significant amounts of low frequency sound energy. This requires a wide air cavity and massive wall leaves. If this cannot be achieved, more massive monolithic construction should be considered.

Structural resonances between wall leaves which are rigidly connected by solid wooden studs can cause poor sound insulation performance of wood stud walls. This problem can be overcome by vibration isolating the two wall leaves with resilient mounts, light weight steel studs, staggered studs or double studs. It appears not to be as serious in the field as it is in the laboratory.

$R_w + C_{tr}$ gives sound insulation values that are in the middle of the range of typical A-weighted sound insulation values for transportation noise. Thus it is fortunate that half the Australian states have adopted $R_w + C_{tr}$ for rating the sound insulation of internal partitions between separate dwellings in the recent update on 1 May 2004 to the Building Code of Australia. This means that in those states we can use the same single number sound insulation rating for both external and internal walls. Hopefully the other states will soon adopt these sound insulation changes.

However a single number rating will not always be adequate for transportation noise. In particular diesel electric locomotive noise will need special consideration because of its very large low frequency sound energy content.

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